The effects of rest interval length and training on quadriceps femoris muscle. Part I: Knee extensor torque and muscle fatigue

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Aim. The purpose of this study was to examine the effects of rest interval on quadriceps femoris (QF) muscle strength and fatigue during short-term, high-intensity training.

Methods. Fifteen healthy males were assessed for isokinetic QF strength, via peak torque (PT), work (WK) and power (PW), at a pre-set angular velocity of 180 degs \(^{-1}\). Quadriceps femoris muscle fatigue was evaluated as the decline in isokinetic work and power (slope) across 30 maximal concentric contractions. Subjects were randomly assigned to 1 of 3 groups: Group 1 (short rest interval), Group 2 (long rest interval), and Group 3 (control-no training). Subjects in Group 1 received a rest period of 40 s in between exercise sets corresponding to a 2:1 rest:work ratio. Subjects in Group 2 received a rest period of 160 s corresponding to an 8:1 rest:work ratio. Groups 1 and 2 performed isokinetic knee extension contractions at 180 degs \(^{-1}\) 2 days per week for 6 weeks.

Results. The results demonstrated a significant increase in QF muscle PT across the 6 week training period in the long rest interval group, and no significant changes in the short rest interval and control groups. Quadriceps femoris muscle work and power were observed to not change significantly across the training period in all 3 groups. The reduction in QF muscle work across the single set of 30 repetitions was observed to decrease significantly in the control group across the 6 week duration; no other significant changes in QF muscle fatigue for work and power were observed.

Conclusion. The major findings of this study suggest that the possibility of different physiological mechanisms of adaptation exist for QF muscle peak torque, work and power, while changes in muscle fatigue resistance may be present when assessed across multiple, rather than a single, bouts of activity.

Key words: Muscle, skeletal, physiology - Fatigue - Muscle fatigue - Physical endurance.

Strength training can enhance performance in sporting activities, assist in the rehabilitation of orthopedic and exercise induced musculoskeletal injuries, and help reduce the incidence of overuse injuries. Optimal strength training programs are designed to manipulate the volume and intensity of exercise in a systematic manner by performing one or more sets of particular exercise interspersed with rest intervals. The inter-set rest interval (the period of time between sets of resistance exercise) is a training factor that has received more attention in the scientific literature regarding its' effects on strength development. It is well accepted that the function of the inter-set rest interval is to allow sufficient time for muscle recovery to take place in between sets of exercise. In this capacity, time-dependent metabolic and non-metabolic mechanisms underlying muscle fatigue may be restored to pre-fatigue levels. As a result, it is speculated that such restoration will promote the maximal generation of muscular tension which is necessary for...
Investigators have demonstrated that a 2 to 3 minute inter-set rest period is sufficient to allow the full recovery of maximal isokinetic quadriiceps torque as compared to rest intervals lasting from 0.5 to 1.5 minutes. However, studies examining the influence of inter-set rest intervals on strength development have been equivocal. Greater strength improvements were observed following short-term strength training using an inter-set rest interval of 3 minutes as compared to rest intervals of 0.5 and 1.5 minutes. Others, however, have challenged this observation by reporting that the development of muscle fatigue through the elimination or minimization of inter-set rest intervals may provide a powerful stimulus for strength development subsequent to training. Furthermore, the impact of this training factor (i.e., rest intervals) on muscle fatigue remains inconclusive, although MacDougall et al. demonstrated a reduction in muscle fatigue during 4 successive maximal-effort cycling sprints following training. The conflicting evidence presented thus far in the literature has subsequently provided an impetus for investigating the time course of strength development as a function of short-term training and recovery duration. Therefore, the purpose of this investigation was to examine the influence of inter-set rest interval length on isokinetic strength and fatigue of the quadriiceps femoris muscle during 6 weeks of isokinetic training in healthy males.

**Materials and methods**

**Subject characteristics**

Subjects for this study included 15 healthy, college-aged males (mean age = 22.4 ± 0.75 years, mean height = 178.5 ± 1.37 cm, and mean body mass = 78.1 ± 2.61 kg). All subjects did not undertake lower extremity resistance training for at least 6 months prior to the investigation. Individuals with a history of cardiovascular disease, diabetes, hypertension and orthopedic pathology or injury were excluded from participating in the study. Written informed consent was obtained in accordance with the Human Subjects Committee of the Biomedical Institutional Review Board of the University of Pittsburgh.

**Procedures**

Following the pre-screening evaluation, subjects were assessed for isokinetic strength and fatigue of the QF muscle for 1 randomly selected lower limb. Subjects were then randomly assigned to 1 of 3 different groups: group 1 was identified as the short rest interval group; group 2 was identified as the long rest interval group; and, group 3 was identified as the control (no training) group. Groups 1 and 2 participated in a 6 week isokinetic training program. All subjects were re-assessed for QF isokinetic strength and fatigue at 2, 4, and 6 weeks following the pre-testing session.

**Isokinetic strength and fatigue**

Isokinetic quadriiceps strength and fatigue was measured by the Biodex System 2 Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY). Prior to all testing and training procedures, subjects completed a dynamic warm-up period that consisted of treadmill walking at 2.5 miles per hour for a period of 5 min followed by muscle stretching. Subjects sat in a comfortable position on the Biodex Accessory Chair and were secured using thigh, pelvic, and torso straps in order to minimize extraneous body movements. The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis of rotation of the dynamometer resistance adapter. Once the subject was placed in a position that allowed for a comfortable and unrestricted motion for knee extension and flexion from a position of 90° of flexion to terminal extension, gravity correction was established by measuring the torque exerted on the dynamometer resistance adapter. Values for the isokinetic variables measured were automatically adjusted for gravity by the Biodex Advantage Software program, version 4.0 (Biodex System Manual). This was accomplished by adding the gravity-dependent torque value to the torque values obtained during the extension contraction phase. Calibration of the Biodex dynamometer was performed according to the specifications outlined by the manufacturers’ service manual. The cushion setting on the control panel for the ends of the range of motion were set to their lowest (hard) setting in order to reduce the effect of limb deceleration on the reciprocal motion, thus obtaining a more reliable torque estimate. Concentric isokinetic knee extension peak torque, work and power were assessed at a pre-set angular velocity of 180 degs-1 across 30 maximal-effort repetitions. Thirty repetitions were selected as this number amounted to a total period of approximately 30 seconds, which is typical of many tests of anaerobic power and capacity. Prior to the test, each subject performed 5 sub-maximal and 2-3 maximal repetitions for warm-up.
up purposes. Windowed values for work (J) and power (Watts) were computed between 10° and 60° of knee range of motion. These windowed values for quadriceps work and power were used in order to standardize the comparison between the 2 tests in this study. Total work was calculated as the summed work values across all 30 repetitions. Average power was also determined over all 30 repetitions. During the testing procedure, the subjects were required to fold their arms across their chest and were given verbal encouragement and visual feedback from the BiodeX computer monitor in an attempt to achieve a maximal effort level. The administration of the test, as well as verbal encouragement, was provided by 1 investigator for all subjects. Isokinetic measures for peak torque, work and power at 180 deg·s⁻¹ on the BiodeX Isokinetic Dynamometer have demonstrated high reliability coefficients ranging from r=0.84 to r=0.97. Quadriceps femoris strength was evaluated via peak torque, work and power. Peak torque was obtained as the single highest torque value that was generated during the 30 repetitions, and was typically achieved by all subjects within the first 5 repetitions. The highest work and power values for a single repetition was also obtained, as was the total work and average power for the 30 repetitions. Quadriceps femoris muscle fatigue was determined by calculating the decline in quadriceps work and power across the 30 repetitions. A 1st order (linear) regression equation was fit to the decline in work and power across the repetitions for each subject, at each isokinetic evaluation. The slope from the calculated regression equation (β-values) for each subject was then obtained to quantify the rate of decrease in quadriceps work (N·m·rep⁻¹) and power (Watt·rep⁻¹) during the exercise bout. Previous measures of quadriceps muscle fatigue, via the slope, have demonstrated high (between-day) test-retest reliability coefficients ranging from ICC=0.78-0.82.

Isokinetic training protocol

Quadriceps training was performed on the BiodeX System 2 Isokinetic Dynamometer at a pre-set angular velocity of 180 deg·s⁻¹. The training protocol is outlined in Table 1. The training program was modified from a previous study such that the number of training sessions per week was reduced from 3 to 2, and the duration was extended from 4 to 6 weeks. This was done to prevent the possibility of an overtraining response (resulting from too many sessions per week) while maintaining a similar amount of work throughout the protocol, as per Pincivero et al. Throughout the 6 week training period, all subjects performed a total of 1440 repetitions, including the repetitions performed during the 4 testing sessions. Five subjects were randomly assigned to 1 of 3 groups: group 1 (training with a short inter-set rest interval), group 2 (training with a long inter-set rest interval), and group 3 (control-no training). Subjects in group 1 received a rest period of 40 s in between exercise sets corresponding to a 2:1 rest-work ratio. Subjects in group 2 received a rest period of 160 s corresponding to an 8:1 rest-to-work ratio. The 160 s rest interval was selected since it has been suggested that adequate recovery with respect to isokinetic strength testing occurs within this duration. Training sessions were separated by at least 72 hours and were performed 2 days per week. Subjects assigned to the control group did not participate in the training program and were asked to abstain from any lower extremity exercises exceeding their typical daily activities for the duration of the study.

Data analysis

A single factor analysis of variance (ANOVA) with repeated measures was performed on QF peak torque, work and power, and fatigue for each group, separately. For each overall F-test, estimates of the effect size index (η²) and statistical power (1-β) were generated. All tests of significance were performed at an error rate of p<0.05.

Results

QF peak torque, work and power

The results for isokinetic QF peak torque are illustrated in Figure 1. Isokinetic peak torque was found to increase significantly across the training period for

<table>
<thead>
<tr>
<th>Week</th>
<th>Sets</th>
<th>Repetitions</th>
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<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>20</td>
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<tr>
<td>5</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>20</td>
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</table>
similiar results were demonstrated for the highest single repetition power for the short rest interval group (F3,12=0.93, p=0.46, η²=0.19, 1-β=0.20), the long rest interval group (F3,12=2.44, p=0.11, η²=0.38, 1-β=0.47), and the control group (F3,12=1.35, p=0.30, η²=0.25, 1-β=0.27). The average pretest-post test change the highest single repetition power value was 9.3%, 12.7%, and 4.2% for the short rest interval group, long rest interval group and control group, respectively. The results from the present study demonstrated that the manipulation of the inter-set rest interval did not have a significant effect on isokinetic quadriceps total work during the training period. These findings were evident as no significant group by time interactions were detected between the 3 groups (F6,36=0.74, p=0.62). The pretest to posttest differences showed a percentage variation of 13.2% and 7.2% for groups 1 and 2, respectively. The results from this investigation also indicated that the inter-set rest interval had no effect on improvements in quadriceps average power during the training period. These findings were demonstrated as no significant group by time interactions were found (F6,36=0.26, p=0.95). Pretest/posttest (week 6) changes in quadriceps average power of 11.3% to 11.6% for groups 1 and 2, respectively, were demonstrated. These variations, however, were not found to be statistically significant (F2,12=0.22, p=0.81) following the 6 week training period between the 3 groups.

Quadriceps femoris isokinetic fatigue

The average reduction in isokinetic QF work and power (i.e., Β values) for each of the 3 groups at each time period (i.e. pre-training, 2, 4, and 6 weeks) are presented in Table II. The results demonstrated no significant changes in QF work fatigue in the short rest interval group (F3,12=0.56, p=0.66), nor the long rest interval group (F3,12=2.0, p=0.17). Subjects in the con-

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**Table II** — Isokinetic quadriceps total work (J) and average power (W) and isometric IEMG activity (μV·s) of the VM and VL muscles during 6 weeks of training (mean±SD - group 1 = short rest interval, group 2 = long rest interval, group 3 = control, non-training).

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test</th>
<th>2nd week</th>
<th>4th week</th>
<th>6th week</th>
<th>Δ (pre-post)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2249±350.7</td>
<td>2352±399.8</td>
<td>2530±452.2</td>
<td>2592±503.7</td>
<td>13.2</td>
</tr>
<tr>
<td>2</td>
<td>2537±356.0</td>
<td>2746±647.3</td>
<td>2757±564.7</td>
<td>2893±609.7</td>
<td>7.2</td>
</tr>
<tr>
<td>3</td>
<td>2712±776.0</td>
<td>2668±649.2</td>
<td>2570±579.9</td>
<td>2700±417.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Average power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>261±66.9</td>
<td>271.8±47.2</td>
<td>268.4±56.9</td>
<td>285.2±39.0</td>
<td>11.3</td>
</tr>
<tr>
<td>2</td>
<td>289±57.8</td>
<td>309±76.2</td>
<td>316.7±62.7</td>
<td>327.8±70.9</td>
<td>11.6</td>
</tr>
<tr>
<td>3</td>
<td>297.8±64.9</td>
<td>294.8±51.5</td>
<td>299.7±64.9</td>
<td>317.1±33.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>
Table IV.—Isokinetic quadriceps femoris muscle work (Nm·rep⁻¹) and power (Watt·rep⁻¹) fatigue slopes across the 6-week training period (mean±SD). Group 1 = short rest interval, Group 2 = long rest interval, Group 3 = control, non-training.

<table>
<thead>
<tr>
<th>Pre-training</th>
<th>2 weeks</th>
<th>4 weeks</th>
<th>6 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QF work</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>-1.88±0.62</td>
<td>-1.72±0.53</td>
<td>-1.65±0.64</td>
</tr>
<tr>
<td>Group 2</td>
<td>-1.72±0.46</td>
<td>-1.53±0.47</td>
<td>-1.73±0.21</td>
</tr>
<tr>
<td>Group 3</td>
<td>-1.86±0.58</td>
<td>-1.76±0.34</td>
<td>-1.32±0.34</td>
</tr>
<tr>
<td><strong>QF power</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>-6.78±2.56</td>
<td>-6.13±1.93</td>
<td>-5.80±2.26</td>
</tr>
<tr>
<td>Group 2</td>
<td>-5.76±1.42</td>
<td>-5.33±1.33</td>
<td>-6.27±0.66</td>
</tr>
<tr>
<td>Group 3</td>
<td>-6.22±1.59</td>
<td>-6.03±0.95</td>
<td>-5.28±1.75</td>
</tr>
</tbody>
</table>

Control group demonstrated a statistically significant decrease in QF work fatigue between the pre-training period and weeks 2 and 4 (F₁,₁₂=4.56, p=0.024, η²=0.53, 1-β=0.75). The results demonstrated no significant changes in QF power fatigue for the short rest interval group (F₁,₁₂=0.53, p=0.67), the long rest interval group (F₁,₁₂=2.25, p=0.14), and the control group (F₁,₁₂=1.46, p=0.28), (Table III).

**Discussion**

The major findings of this study indicated that the use of a comparatively longer inter-set rest interval (160 s) during short-term (6 weeks) isokinetic training resulted in a significant improvement in peak torque, whereas the short rest interval and control groups experienced no significant changes. Quadriceps femoris muscle work and power were observed to not change significantly across the training period for the training and control groups, suggesting that physiological mechanisms driving these variables may be different than those for peak torque. Quadriceps femoris muscle fatigue was observed to be unchanged, with the exception of the control group for work, across the 6 week duration.

**QF peak torque, work and power**

The theoretical benefit of incorporating relatively longer inter-set rest intervals is the enhancement of active muscle tension through a number of time-dependent recovery mechanisms. Such mechanisms involve the re-synthesis of intramuscular stores of PCR as well as enhancing the elimination and limiting the production of metabolic end products such as lactic acid, ammonia and the diprotonated form of inorganic phosphorus. It was, therefore, speculated in the present investigation that the greater muscle force produced during training, as afforded by the longer rest period, would enhance strength development. In terms of peak torque, this was illustrated in the long rest interval group as a significant improvement was observed across the training period, as opposed to the short rest interval and control groups.

Similar results were observed by Robinson et al., who found a significantly greater increase in 1-RM squat strength in subjects that utilized a 3 min-inter-set rest interval as compared to a 1.5 min and a 30 s rest period, following 5 weeks of training. Contrary, the elimination of rest periods during a short-term period of training was shown by Rooney et al., to significantly contribute to strength development. It should be noted that this particular rest period referred to the time interval in between repetitions of a single set of 6 to 10 repetitions of elbow flexion resistance exercise. It may be argued, therefore, that the provision of a rest interval in such a case may have been detrimental to strength development; a single, continuous set of 6 to 10 repetitions of a particular resistance exercise may have been necessary to stimulate an adaptation response.

Further evidence demonstrated that the significant strength improvements of the quadriceps femoris muscles following 4 weeks of isokinetic training were not significantly different between short and long rest interval lengths, although hamstring work and power increased significantly more during the training period when relatively longer rest intervals were utilized. Over a short-term period of training, such as that used in the present study, contributions to an increased ability to generate force may arise via a number of mechanisms, which include neuromuscular, enzymatic, and morphological adaptations. The allowance of muscle recovery during high maximal effort contractions may prove to be a significant factor for facilitating the enhancement of instantaneous torque output (i.e., peak torque) over a short-term period of resistance training.
not statistically significant. It should be noted that these percent variations appear to lie within the range of strength improvements observed in previous studies.20-34 Specifically, investigators have demonstrated statistically significant improvements in isokinetic strength following training that have ranged from 4% to 18.4%.30,31,33,34 However, Housh et al.33 found that 8 weeks of isokinetic training at 120 degs⁻¹ resulted in a statistically non-significant increase in quadriceps peak torque of 11.2%. The results from the present investigation appear to concur with those of Housh et al.,33 as the aforementioned variations in quadriceps femoris work and power appear to have increased, albeit statistically non-significant. It is also noteworthy that the pretest/post-test changes for the control group fell within the range of test-retest error estimates for isokinetic knee extension at 180 degs⁻¹. The findings of the present investigation may also suggest an apparent limitation of the current training protocol for significantly enhancing quadriceps femoris strength. It is possible that the frequency of training (days/week), the duration of the training period, and the total number of repetitions performed may be important determinants of muscle strength gains. This notion, however, does not appear to be supported by previous studies.2,30-32,33-38 An examination of these training variables at various isokinetic velocities, including the present study, have demonstrated no significant correlation between training frequency, duration and total number of repetitions performed with isokinetic strength improvements (Table IV).

**Quadriiceps femoris muscle fatigue**

The development of muscle fatigue during repetitive, maximal effort contractions is driven by numerous physiological mechanisms ranging from non-metabolic8,9,39 to metabolic7,30 origins. This “...reduction in the force generating capacity of the total neuromuscular system...”40 has been observed to follow a negative linear trend during maximal-effort, short-duration (i.e., approximately 30 s) bouts.20,39 As a function of training, preliminary evidence suggests that muscle fatigue resistance may be enhanced. Duchateau and Hainaut41 found that 3 months of sub-maximal (30-40% of maximal force) training of the adductor pollicis muscle in 8 young adults reduced the decrease in force output during a 60 s period of ulnar nerve stimulation at 30 Hz. Following 7 weeks of sprint cycling training, MacDougall et al.14 found significant improvements in peak and total power output during 4 successive 30 s Wingate cycling bouts in 12 young males. The improvements over pre-training values were observed across bouts 2 to 4, whereas no significant training effects were noted for the first 30 s bout. As a result, fatigue resistance enhancement appears to have manifested, as the subjects were able to generate greater power during the successive bouts. In a design similar to the present investigation, Costill et al.30 trained 5 males with isokinetic knee extension contractions for 7 weeks, and observed a significant improvement in mean power output over the first 30 s of a 60 s maximal effort test performed at 180 degs⁻¹; however, the decline in power output over the repeated contractions was found to be greater in the trained, than the non-trained limb, apparently decreasing fatigue resistance. The findings of the present study demonstrated no significant training induced changes in quadriceps femoris muscle fatigue within the single bout of 30 knee extension contractions. As muscle fatigue was quantified as the reduction in knee extensor work and power across 30 repeated contractions, rather than successive bouts, post-training similarities may have been present with MacDougall et al.14 with respect to the non-significant changes in total power output over the first 30 s cycling test. Although the objective of the current study was to examine rest interval and training effects on quadriceps femoris muscle fatigue over a single bout of repeated contractions, an improvement in fatigue resistance may have been observed over multiple bouts. It is important to note that the present results were not supportive of those observed by Duchateau and Hainaut.41 Fatigue resistance enhancement of the adductor pollicis muscle, which was demonstrated over 60 s of ulnar nerve stimula-
tion, is suggestive of a beneficial training effect as a higher degree of muscle force was sustained. It is clear that methodological differences may have accounted for the dissimilar findings with the present study. The relatively longer training period of 3 months, the trained muscle (adductor pollicis) and the method to invoke muscle fatigue (ulnar nerve stimulation) are all significant factors that mediated the training response. It has been shown that training involving maximal-effort contractions induce an increase in enzyme activity such as phosphofructokinase, glycogen phosphorylase, and citrate synthase, thereby enhancing glycolytic capacity. In terms of the inter-set rest interval length, very little evidence exists regarding its efficacy on mediating muscle fatigue following training. One such study examined the period of rest in between days of sprint cycling training in 10 healthy males. Those subjects utilizing 2 days ofrest in between training sessions, as opposed to the group who trained on a daily basis, experienced significantly greater cycling performance during a 50 s Wingate protocol post-training. The group of 5 males that were not afforded rest did not demonstrate significant post-training changes in cycling performance. It was also noted by Parra et al. that the inter-set rest interval rest:work ratio of the training program was 24, as compared to 2 and 8 for the present investigation, 8 in the MacDougall et al. study, and 11 in the Linossier et al. study. Although not evaluated in the present investigation, an adaptation in glycogen utilization, via an increase in hexokinase activity, appears to be a significant physiological change with the relatively lower rest:work ratios.

Conclusions

Resistance training has come to be an important component in athletic, recreational and rehabilitation programs. The length of the inter-set rest period may prove to be a significant factor in facilitating strength enhancement over a given training period. The findings of the present study clearly demonstrate that use of a relatively longer inter-set rest period resulted in significant increase in QF muscle peak torque over a short period of training. The major limitation of the present investigation was the low number of subjects randomly assigned to each group; this effect on decreasing statistical power would have undoubtedly increased the chance of committing a type II error, as suggested by the range of observed strength improvements in previous studies. Despite the finding that muscle fatigue did not significantly change as a function of the inter-set rest interval length during the training period, the results of the present study suggest that further inquiry into the optimal recovery period is warranted.

References

17. Ling W, Chen FC, McDonough AL. Evaluation of the cushion set-